AD NUMBER

AD479938

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; SEP 1964. Other requests shall be referred to Air Force Materials Laboratory, Wright-Patterson AFB, OH 45433.

AUTHORITY

AFML USAF ltr, 12 Jan 1972

R7 8527

479938

(1)

(6) EXPLORATORY EVALUATION OF
FILAMENT-WOUND COMPOSITES FOR TANKAGE OF
ROCKET OXIDIZERS AND FUELS.

(14)

QUARTERLY PROGRESS REPORT NO. 0873-01-1
September 1964

(9) Quarterly progress rept. no. 1, 1 Jun-
1 Sep 64,

To

Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
~~Wright-Patterson Air Force~~ Base, Ohio

(10) M. J. Sanger, F. J. Darm...,
R. W. Buxton,
R. L. Kocher
M. Seginnato.

(15) Contract No. AF 33(615)-1671



(11) Sep 64,

73

(12) 25p.

(Prepared by the Structural Materials Division of the
Aerojet-General Corporation, Von Karman Center, Azusa, California)

3/238

SQT-30052

## FOREWORD

This is the first quarterly progress report issued in partial fulfillment of Air Force Contract No. AF 33(615)-1671 and covers the work performed during the period of 1 June to 1 September 1964. The study is administered by the Materials Laboratory, Research and Technology Division, Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio. The work is being performed under the technical direction of Mr. T. J. Reinhart, Jr., Project Engineer. The primary objective of this program is the exploratory evaluation of filament-wound composites for tankage for rocket oxidizers and fuels.

The study is being conducted at the Structural Materials Division, Von Karman Center, Aerojet-General Corporation under the direction of M. J. Sanger, Project Engineer. Others who have cooperated in the study and in the preparation of this report are: F. J. Darms, Manager of Structural Engineering Department, R. W. Buxton, Supervisor Structural Programs Section, P. L. Kocher, Contract Coordinator, and M. Segimoto, Resin Chemist. This report has been given corporate internal number 0873-01-1.

AEROJET-GENERAL CORPORATION

F. J. Darms

F. J. Darms, Manager
Structural Engineering Department
Structural Materials Division

## ABSTRACT

This ~~quarterly progress~~ report covers the initial work performed in the first two phases of the program, I-Resin Materials Study and II-Liner Materials Study. During this period, a literature survey was made to obtain background on the compatibility of these materials with the following oxidizers and fuels, as shown in Exhibit A of Contract No. AF 33(615)-1671: UDMH-Hydrazine (50/50); $N_2O_4$; Pentaborane; and $ClF_3$.

This literature survey indicated that very few of the resins commonly used in filament-wound structures possessed a high degree of compatibility with the propellants of interest. It was also noted that polymeric films were permeable to these fluids.

Preliminary screening tests of the chemical compatibility of resins and liner materials were made to confirm the literature reports and to provide direction for more concentrated studies on these materials. The results of these tests confirmed, in general, the reports obtained in the literature survey and indicated the necessity for a barrier type liner. A metallic liner appears to be mandatory for the more corrosive propellants.

CONTENTS

## I. INTRODUCTION AND SUMMARY

Contract No. AF 33(615)-1671 was undertaken to provide the U.S. Air Force with information on materials and fabrication techniques that could be used in the design of reliable filament-wound tankage for storable propellants in a space environment. The study involves the exploratory evaluation of materials by a literature survey and laboratory testing of samples to permit selection of: resin binders with maximum resistance to the fluids involved; and liner materials that will effectively prevent contact of the fluids with the tank structure. Also included are the development of fabrication techniques and environmental testing of subscale tanks with the propellants in order to validate the studies. The results of the material, fabrication and testing studies are to be translated into a design for a full-scale prototype tank. A space experiment will be defined to evaluate the efficiency of filament-wound tankage in a space environment.

This report covers the preliminary results of the resin and liner material studies. A review of the literature on chemical compatibility of materials with Aerozine-50 (UDMH-hydrazine 50/50), $N_2O_4$, pentaborane, and $ClF_3$ has been conducted to ensure maximum use of all available information, and to reduce lead time for testing and design work. Laboratory screening studies were conducted to check the literature reports and to provide a sound basis for material selection.

The following is a summary of the literature survey and the material screening studies:

A. The resin binder systems commonly used in filament winding have a low degree of compatibility with rocket fuels and oxidizers.

B. Novolac-type epoxies and polyepoxides show moderate to good resistance to rocket fuels.

C. Phenolic resins have fair compatibility with $N_2O_4$ for short exposure periods.

D. Organic resins and polymers can form impact-sensitive mixtures with pentaborane.

E. $ClF_3$ rapidly oxidizes all organic materials except fluorinated polymers.

F. Stainless steels are corrosion resistant to $N_2O_4$.

G. Monel metal and some aluminum alloys are corroded by $N_2O_4$.

During the period covered by this report, possible problem areas were considered and plans were made for resolving these, in so far as possible, before the fabrication of the subscale tanks. The structural compatibility of metallic liner materials with filament-wound cases has been given great emphasis in current studies.

## II. TECHNICAL DISCUSSION

### A. RESIN MATERIALS STUDY

#### 1. Literature Survey

Although the information available in the literature regarding compatibility of resin binder systems with the propellants of interest was rather limited, the investigators are apparently unanimous in the belief that the common resin binders would not withstand direct contact with these corrosive materials for long periods of time. However, variations in degree of resistance between resins do exist; Aerojet Report TM 151 LRP (Reference 1) reported that the cyclic and novolac epoxies, phenolics, and blended compositions possess a moderate degree of resistance under ambient temperature conditions. The novolac epoxies, because of their higher cross-link density than the Bisphenol A type, appear to have good compatibility with Aerozine-50 (UDMH-hydrazine 50/50) fuel. Nadic methyl anhydride and $BF_3$400 cured systems have also shown some promise in compatibility with the hydrazine type fuels.

In the study reported in Reference 1, not many of the resin systems withstood more than a few hours exposure to $N_2O_4$. The Boeing Company found that an epoxy resin/glass matrix supporting a 5-mil Teflon film showed a very rapid reduction in flexural strength from the permeation of $N_2O_4$ through the film (Reference 2). Phenol formaldehyde and melamine formaldehyde resins may be promising candidates for binders for filament-wound tankage containing $N_2O_4$ because of their known resistance to oxidizing media. However, processing problems and a tendency toward crazing, both of which are characteristic of these resins, may prevent their acceptance.

Although there is little information on the compatibility of resin compositions with pentaborane, it has been observed that this fuel reacts with any organic compound containing a reducible functional group. The rate of reaction depends upon the type and concentration of these functional groups. It has been reported that pentaborane forms shock-sensitive mixtures with a number of organic compounds, including polysulphides, ethers, esters, ketones, and chlorinated ethers (References 3 and 4).

$ClF_3$ is known to be a very corrosive oxidizer and will cause detonation of many polymers and organic materials (Reference 5). Instances have been reported of a violent incendiary reaction when an epoxy compound comes in contact with $ClF_3$ (Reference 6). A completely impermeable liner is obviously required for filament-wound tankage containing $ClF_3$.

2. Experimental Program

Although the literature survey indicated that organic resin systems will not withstand continuous exposure to rocket oxidizers and fuels, it is desirable that maximum compatibility be obtained to provide some degree of protection for filament-wound structures in case of spillage or minor permeation of propellant through the liner.

The identification and composition of the candidate resin systems are shown in Table 1. The forms in which these systems are available, and the probable processing techniques for each, are shown in Table 2.

A 2-in.-dia disc was cast from each resin system and the Barcol hardness determined on each. The disc was then cut into two pieces and spot-tested by immersion in Aerozine-50 and $N_2O_4$ for 2 days at 70°F. At the end of this exposure, the specimens were removed, examined for appearance, and the Barcol hardness again determined. The results of the exposure to the propellants are shown in Table 3. Figures 1 and 1a show the appearance of the specimens after exposure. Inasmuch as most of the candidate resin systems are quite high in viscosity, considerable difficulty in casting smooth specimens was encountered; therefore, the deep pock marks appearing in the photographs were present in the original specimens and were not due to attack by the immersion medium. However, surface erosion is obvious on the less-resistant resin systems.

The results of these spot tests confirmed, in general, the information on compatibility of resins with Aerozine-50 and $N_2O_4$ that had been reported in the literature. That is, the novolac epoxies, as represented by RS-4, RS-5, RS-6 and RS-1, showed good resistance to either one or both of the propellants. RS-10, a phenolic resin, showed good resistance to both propellants but RS-12, another phenolic, gave a disappointing performance. It will be noted that blending of novolac epoxies with Bisphenol A, to achieve improved processing, severely reduced the propellant resistance of these systems. The high viscosity of the novolac epoxies will probably require the use of a pre-preg technique for application of the resin to the glass filaments. The melamine formaldehyde resins, RS-8 and RS-9, were outstanding in compatibility with the propellant but were too brittle for hardness determinations and of doubtful processability as resin binders for filament winding.

The five most promising resin systems from the spot tests were cast into 1/8-in. slabs and flexural test specimens prepared for further screening tests. RS-4, RS-5, RS-6, RS-10, and RS-11 were chosen for this program. The specimens were exposed to $N_2O_4$ and Aerozine-50 for 7 days at 100°F. RS-10 was not included in this test because of severe blistering of the specimens. The remaining four systems decomposed completely during exposure to the $N_2O_4$ at 100°F. The results of the exposure of the specimens to Aerozine-50 at 100°F were inconclusive and will be repeated.

Resin systems RS-4, RS-5, RS-6, RS-10 and RS-11 were then subjected to an exposure of 7 days at 70°F, to Aerozine-50 and $N_2O_4$. Barcol hardness, flexural strength, and weight determinations were made before and after exposure to these propellants. The results of these tests are shown in Table 4; the appearance of the specimens is shown in Figure 2. This screening study shows that RS-4, RS-6, and RS-11 (the novolac epoxies, a polyepoxide, and blends with Bisphenol A epoxies) have the highest degree of compatibility with Aerozine-50. The combination of Kopox 170 with DER 332, cured with $BF_3$400, showed fairly good resistance to $N_2O_4$ even though the flexural strength had dropped by one-half. The phenolic system, TS-10, also was in fairly good condition, although the specimens could not be tested for flexural strength because of warpage that occurred during casting. The remainder of the resin systems were quite severely degraded by exposure to the $N_2O_4$.

The results of the 7-day exposure screening tests to Aerozine-50 and $N_2O_4$ indicate that two resin systems, RS-4 and RS-11, of similar composition, have the highest degree of compatibility with the fuel, whereas two other systems, RS-6 and RS-10, are most resistant to the oxidizer. Longer exposure tests to these propellants at two temperatures are now underway to substantiate these preliminary observations.

B. LINER MATERIALS STUDY

1. Literature Survey

Reports from the literature indicate that a major effort has been made in the search for elastomeric and plastic liner materials which are compatible with rocket fuels and oxidizers. A number of materials have been found useful for various applications involving contact with the less corrosive propellants. However, after long exposure and exposure at higher-than-ambient temperatures, the polymeric materials exhibit swelling, loss of strength, and absorption of the propellant. Also, the investigators who have made these studies concur in their findings that no organic lining material is completely impermeable to the propellants. For containment of the more corrosive fluids such as $N_2O_4$, pentaborane, and $ClF_3$ a corrosion-resistant metallic liner is indicated.

Following is a brief summary of the literature survey by propellants with the recommended liner materials for each.

a. Aerozine-50 (UDMH-Hydrazine 50/50)

Fluorocarbons, for example, Teflon and Kynar, resist attack by Aerozine-50 for long periods of time but are permeable to this fluid (Reference 1). Kel-F was found to be resistant to Aerozine-50 but showed stress cracking after long exposure periods (Reference 1). Resin-cured butyl compounds have been found compatible with Aerozine-50, but swell slightly after long exposure periods and are permeable (Reference 5). Diamine nylons have shown excellent resistance to Aerozine-50 (Reference 7). Polyethylene and polypropylene absorb Aerozine-50 but no chemical attack was observed (Reference 7). EPR and ClS-1, 4 polybutadiene compounds showed good compatibility with hydrazine type fuels (Reference 5). Most aluminums, stainless steels, nickel, chromel, and Monel are compatible with hydrazine-type propellants (Reference 8). Aluminum-Teflon laminates (Reference 9) and aluminum-butyl rubber laminates are reported to withstand attack by Aerozine-50 and to show no permeability to this fluid (Reference 5).

b. $N_2O_4$

Although Teflon TFE and FEP are the most compatible of the plastic materials when exposed to $N_2O_4$, they absorb this propellant and expel it by outgassing when exposed to a vacuum (Reference 7). These plastic films are also quite permeable to $N_2O_4$ (Reference 1). Aluminum alloys 1100, 2024, and 5052, and stainless steels 303, 304, and 347 were rated as good in $N_2O_4$ service (Reference 8). However, other investigators do not consider aluminum 2024 as being acceptable when the water content in $N_2O_4$ is over 0.2% (References 10, 11, and 12). The stainless steels are resistant to $N_2O_4$ regardless of the water content (Reference 11).

c. Pentaborane

Of the non-metallic materials, Teflon, Kel-F-5500, Viton A and B are considered compatible with pentaborane (References 3 and 4). Stainless steels 302, 304, 321, 347, and 18-8, aluminum alloys 5052-S, 6061-T6, 7075-T6, 2024-T3, 3003-H14, and 356-T6, Monel, nickel, magnesium, titanium, copper, brass, and Hastelloy have been found compatible (References 3 and 4).

d. $ClF_3$

No non-metallic materials are recommended for use with $ClF_3$ because of the extremely corrosive nature of this propellant (Reference 6). The compatible metals include the 300 series stainless steels, aluminum alloys, 356, 1100, 2024, 5052, 6061, 6063, chromium-plated steel, copper, nickel, Monel, K-Monel, Rene 41, nickel-base Superalloy, and indium (Reference 13). In one study it was noted that there was no evidence of stress corrosion on any of the exposed metals either by visual examination or by the dye penetrant inspection procedure (Reference 6). It was also found in this study that passivation by $ClF_3$ was unnecessary for reducing corrosion of properly cleaned metals. An Aerojet study of metals compatible with hydrazine, $N_2O_4$, $B_5H_9$, $ClF_3$, and liquid fluorine concluded that " ... the metal approaching complete compatibility with all propellants under consideration is Type 347 stainless steel ..." (Reference 14).

2. Experimental Program

Metallic liner materials appear to be required for the more corrosive rocket fluids. However, in order to achieve maximum weight economy in filament-wound tankage very thin linings are necessary. The lining must tolerate the expansion and contraction of the filament-wound chamber during temperature and pressure cycling. It must also have sufficient elongation to permit the design of optimum stress levels in a glass filament-wound structure. This is estimated to be from 1-1/2 to 3% elongation.

Inasmuch as thin metallic liners will be required for filament-wound tankage for storable propellants because of weight limitations, the corrosion resistance of these metals is quite important. Therefore, a study was made of the corrosion resistance to $N_2O_4$ by the candidate metallic liner materials to substantiate the results reported in the literature. Two 2- by 7/8- by .012-in. specimens of each of the metals were weighed and then immersed in $N_2O_4$ at $160^oF$ for 163 hours. At the end of this time, the specimens were re-weighed and examined for evidence of discoloration. The corrosion rate, in mils per year, was calculated from the weight-loss measurements. The results of this study are shown in Table 5.

The results, in general, confirm the observations reported in the literature. It will be noted that the Teflon peeled away from the aluminum in the laminate construction. This would be very unsafe if it occurred in a propellant tank. However, Dr. Church of the Swedlow Co., in a private communication, advised that the normal procedure in the fabrication of metal liners is to expose the metal side of the aluminum-Teflon laminate to the fuel (Reference 15). He stated that a coating, such as Teflon, over the metal liner increased the service life of the liner. The corrosion rate of the Type 2024 aluminum alloy was definitely measurable and indicates the presence of moisture in the $N_2O_4$. A slight discoloration on the surface of the Al-2024 was further evidence of corrosion of this metal. The high corrosion rate of the Monel metal shown on this test would rule out the use of this metal for containment of $N_2O_4$. Al-1100, and stainless steels 304 and 347, appear to be acceptable for use as a liner for $N_2O_4$ tankage.

Although non-metallic materials cannot be considered as candidates for the liner of tanks for the more corrosive propellants, they may be useful as laminates with metal foils. Compatibility tests of films made from Teflon, Kynar, polyethylene, and propylene are being made to determine the effect of exposure to Aerozine-50, $N_2O_4$, and $ClF_3$ on strength properties and permeability of the polymeric liner materials.

A brief spot test was made of the compatibility of these materials, along with a butyl rubber compound, to $ClF_3$. Approximately 1 to 2 cc of liquid $ClF_3$ was allowed to flow across the material under test. The polyethylene and polypropylene immediately ignited upon contact with the $ClF_3$ and burned quite fiercely until they were consumed. Although ignition of the butyl rubber did not occur it was badly eroded and became quite brittle. Teflon and Kynar will be subjected to additional short-term tests in the $ClF_3$.

C. FUTURE WORK PLANNED

1. Concentration of Effort

Inasmuch as the primary objective of the program is the determination of materials, constructions, and fabrication techniques that will produce the most effective filament-wound tankage for storable propellants, the emphasis will be concentrated on achieving this objective. Material studies will be continued in an attempt to provide a sound basis for choice of the most resistant binder systems, the least permeable liners, and the most permanent composite structures. The containment of these very corrosive propellants is recognized as a very difficult problem because of the extremes in temperature, pressure, and vacuum that will be encountered in a space environment. Each element of the tankage must be chemically resistant and structurally sound to resist these deteriorating influences.

2. Investigation of New Concepts in Design and Testing

The background of information from the literature and the experimental program has indicated problem areas that can be anticipated. It is known that the resin binder system of the filament wound case of the tankage must be completely separated from the corrosive fluids such as $N_2O_4$ and $ClF_3$ or catastrophic ignition can occur. Metals are known that are not corroded by these oxidizers. However, in the case of $ClF_3$, the passivated surface of the metal liner may flake off during flexing and continually expose a fresh surface for attack. This would result in weakening of the liner and eventual failure. It is, therefore, essential that a test method to simulate this action be devised. A pressure operated plunger or diaphragm within an exposure chamber would accomplish this.

Since the metal liners for the filament wound tankage must be fabricated by welding of pre-formed sections, the leakage through weld areas could be a major problem. Although metals are quite impermeable to the propellants of interest, weldments are known to be much less so. It has been reported that the permeability of a welded area of 3 to 3-1/2 mil stainless steel under a driving pressure of 5 psi of helium may be as high as 3-1/2 cu in./sq ft/year (Reference 15). This problem area will be thoroughly investigated.

Another possible problem area is the flex fatigue of metal liners resulting from expansion and contraction of the filament wound case during temperature and pressure cycling. This has been reported by several investigators (References 2 and 15). The use of a patterned type metal liner appears to be a possible solution of this problem. Studies of various pattern designs have been initiated to provide this solution. A biaxial stretching device is being fabricated for the study of flex fatigue of pattern designs for cryogenic tankage and will be used in the current program on filament-wound tankage for storable propellants. A study will also be made of the correlation of the basic properties of candidate metal liner materials, as shown in Table 6, with the performance of these metals under biaxial stretching tests. It is also planned to confirm the laboratory flex-fatigue studies by pressure cycling of filament-wound tanks. More extensible filaments than glass will be used in these tanks to permit high strain levels in the structure with reasonable thicknesses and thereby simulate the conditions that will be encountered in full-scale tankage. The information and data obtained from these studies should provide a sound basis for the design of efficient structures for the containment of storable propellants in a space environment.

## REFERENCES


1. R. M. Lydon, The Effects of Nitrogen Tetroxide and Aerozine-50 on Non-Metallic Materials, Aerojet-General TM 151 LRP, 28 December 1962.

2. D. Pollman and R. E. Jacobsen, Feasibility Demonstration of the Design, Fabrication, and Testing of Filament-Wound Fiberglass Liquid Propellant Tanks The Boeing Company, Aero-Space Division. Report SSD-TR-61-45.

3. Mechanical System Design Criteria Manual for Pentaborane, AF/SSD-TR-61-3, Rocketdyne, Contract AF 33(616)-6939, September 1961.

4. Pentaborane Handling Manual, AF/SSD-TR-61-10, Rocketdyne, Contract AF 33(616)-6939, September 1961.

5. Joseph Green, N. B. Levine, and R. C. Keller, "Elastomers for Liquid Rocket Fuel and Oxidizer Application," Ind. and Eng. Chem., 2, 2, June 1963. Contract AF 33(616)-7227.

6. The Compatibility of Materials with Chlorine Trifluoride, Perchloryl Fluoride and Mixtures of These, WADD Technical Report 61054. Pennsalt Chem. Corp., February 1961.

7. J. J. Shore, Non-Metallic Materials for Nitrogen Tetroxide and Aerozine-50 Exposure, Aerojet-General Report No. MN-256, August 1960.

8. Compatibility of Rocket Propellants with Materials of Construction, OTS PB 161215, Battelle Memorial Institute, September 15, 1960.

9. Hardesty, Minutes of Technical Forum on Expulsion Bladders and Tank Liners for the Containment of Corrosive and Cryogenic Fuels, Swedlow Inc., 21 May 1963.

10. Mechanical System Design Criteria Manual for $N_2O_4$, AF/SSD-TR-61-5, Rocketdyne, September 1961.

11. M. L. Muchison and T. F. Barton, Compatibility Studies of Metals with Nitrogen Tetroxide and Aerozine-50, Aerojet-General Report No. MN-155-2, 11 August 1960.

12. Mechanical System Design Criteria Manual for $N_2O_4$, AF/SS-TR-61-5, Rocketdyne, September 1961.

13. Chlorine Trifluoride Handling Manual, AF/SSD-TR-61-9, Rocketdyne, September 1961.

14. Prototype Propellant Testing System, RTD-TDR-63-3, Aerojet-General, February 1963.

15. Dr. A. Church, Swedlow Inc., Private Communication, August 21, 1964.

## TABLE 1

### RESIN MATERIALS SCREENING STUDY
### COMPOSITION OF RESIN SYSTEMS

| Identification | Composition | Type of Resin | Source of Resin |
|---|---|---|---|
| RS-1 | Epon 1031 - 50.00 | Novolac epoxy | Shell Chemical Co. |
| | Epon 828 - 50.00 | Bisphenol A epoxy | Shell Chemical Co. |
| | MNA - 90.00 | | |
| | BDMA - 0.55 | | |
| RS-2 | Epon 1031 - 50.00 | Novolac epoxy | Shell Chemical Co. |
| | DER 322 - 50.00 | | |
| | $BF_3$-400 - 1.00 | | |
| RS-3 | Epon 1031 - 50.00 | Novolac epoxy | Shell Chemical Co. |
| | DER 332 - 50.00 | Bisphenol A epoxy | Dow Chemical Co. |
| | BDMA - 0.25 | | |
| RS-4 | DEN 438 - 75.00 | Novolac epoxy | Dow Chemical Co. |
| | DER 332 - 25.00 | Bisphenol A epoxy | Dow Chemical Co. |
| | $BF_3$-400 - 2.00 | | |
| RS-5 | DEN 438 - 49.50 | Novolac epoxy | Dow Chemical Co. |
| | MNA - 50.50 | | |
| | BDMA - 0.25 | | |
| RS-6 | Kopox 170 - 75.00 | Polyepoxide | Koppers Co. |
| | DER 332 - 25.00 | Bisphenol A epoxy | Dow Chemical Co. |
| | $BF_3$-400 - 2.00 | | |
| RS-7 | Laminac 4173 100.00 | Polyester | American Cyanamid |
| | MEK Peroxide 2.00 | | |
| | DMA - 0.025 | | |
| RS-8 | Cymel 431 - 100.00 | Melamine formaldehyde | American Cyanamid |
| RS-9 | Cymel 430 - 100.00 | Melamine formaldehyde | American Cyanamid |
| RS-10 | U.S.P. No. 46-100.00 | Phenol formaldehyde | U.S. Polymeric |

TABLE 1 (cont.)

| Identification | Composition | Type of Resin | Source of Resin |
|---|---|---|---|
| RS-11 | DEN 438 - 100.00<br>$BF_3$-400 - 2.00 | Novolac epoxy | Dow Chemical Co. |
| RS-12 | USP No. 36 - 100.00 | Phenol formaldehyde | U.S. Polymeric |
| RS-13 | 91LD - 100.00 | Phenol formaldehyde | Cincinnati Testing Lab. |
| RS-14 | L-70 - 100.00 | Styrene-Butene-Vtn.Tol. | Emerson & Cuming, Inc. |

Abbreviations

| | |
|---|---|
| MMA | Methyl nadic anhydride - curing agent |
| BDMA8 | Benzyldimethylamine - accelerator |
| $BF_3$-400 | Boron Trifluoride monoethylamine - latent curing agent |
| MEK Peroxide | methyl ethyl ketone - curing agent |
| DMA | dimethyl aniline - accelerator. |

TABLE 2

RESIN MATERIALS SCREENING STUDY
PROCESSABILITY OF CANDIDATE RESIN SYSTEMS

| Resin System No. | Form Available | Processing Technique |
|---|---|---|
| RS-1 | Viscous fluid | Prepreg. Too viscous for in-process |
| RS-2 | Solid | Prepreg. Solvent solution application |
| RS-3 | Viscous fluid | Prepreg. Too viscous for in-process |
| RS-4 | Viscous fluid | Prepreg. Too viscous for in-process |
| RS-5 | Slightly viscous fluid | Satisfactory for in-process application |
| RS-6 | Viscous fluid | Prepreg. Too viscous for in-process |
| RS-7 | Non-viscous fluid | Satisfactory for in-process application |
| RS-8 | Solid | High-pressure molding process |
| RS-9 | Solid | High-pressure molding process |
| RS-10 | Solvent system | Prepreg. Venting required |
| RS-11 | Viscous fluid | Prepreg. Too viscous for in-process |
| RS-12 | Solvent system | Available as prepreg only |
| RS-13 | Solvent system | Available as prepreg only |
| RS-14 | Non-viscous fluid | Satisfactory for in-process application |

## TABLE 3

### RESIN MATERIALS SCREENING STUDY

(Exposure of Two Days at 70°F in Aerozine-50 and $N_2O_4$)

| Resin System No. | Original Barcol Hardness | Condition After Exposure: Aerozine-50 Barcol | Aerozine-50 Appearance | $N_2O_4$ Barcol | $N_2O_4$ Appearance |
|---|---|---|---|---|---|
| RS-1 | 37 | 41 | Rough surface | 33 | Severely degraded |
| RS-2 | Too brittle | Too brittle | Rough surface | Completely degraded | |
| RS-3 | 38 | 43 | Rough surface | 34 | Severely degraded |
| RS-4 | 38 | 32 | Good | 40 | Degraded |
| RS-5 | 33 | 33 | Good | 28 | Slight surface attack |
| RS-6 | 41 | 33 | Good | 28 | Slight surface attack |
| RS-7 | 28 | Completely degraded | | Completely degraded | |
| RS-8 | Too brittle | Too brittle | Good | Too brittle | Good |
| RS-9 | Too brittle | Too brittle | Good | Too brittle | Discolored |
| RS-10 | 50 | 32 | Good | 54 | Good |
| RS-11 | 36 | 31 | Good | 38 | Rough surface |
| RS-12 | 34 | Completely degraded | | 20 | Soft, mushy |
| RS-13 | Porous | Too porous to test | | Too porous to test | |
| RS-14 | 67* | 62* | Good | Completely degraded | |

*"D" Durometer hardness readings.

## TABLE 4

## RESIN MATERIALS SCREENING STUDY

(Exposure of Seven Days at 70°F in Aerozine-50 and $N_2O_4$)

| | Original Properties* | | Properties After Exposure* | | | |
|---|---|---|---|---|---|---|
| Resin System | Barcol Hardness | Flexural Strength, psi | Barcol Hardness | Flexural Strength, psi | Weight Change, % | Visual Condition of Specimen |
| | | (a) Aerozine-50 | | | | |
| RS-4 | 30 | 15,700 | 34 | 16,200 | +0.42 | No change |
| RS-5 | 35 | 15,860 | Major portion of material dissolved | | | |
| RS-6 | 42 | 10,710 | 41 | 5,470 | +0.36 | Good |
| RS-10 | 56 | No test** | 31 | No test** | +9.40 | Faded, no change |
| RS-11 | 30 | 16,280 | 34 | 15,540 | +0.42 | No change |
| | | (b) $N_2O_4$ | | | | |
| RS-4 | 30 | 15,700 | Major portion of material dissolved | | | |
| RS-5 | 33 | 15,860 | - | Degraded | +5.70 | Severely pitted |
| RS-6 | 41 | 10,710 | 46 | 4,920 | +0.81 | Good |
| RS-10 | 54 | No test** | 56 | No test** | +1.39 | Slightly faded, good |
| RS-11 | 30 | 16,280 | - | Degraded | - | Severely pitted |

*Property values are averages of three tests.

**Specimens too distorted for flexural strength test.

TABLE 5

LINER MATERIALS SCREENING STUDY
CORROSION OF METALS BY $N_2O_4$

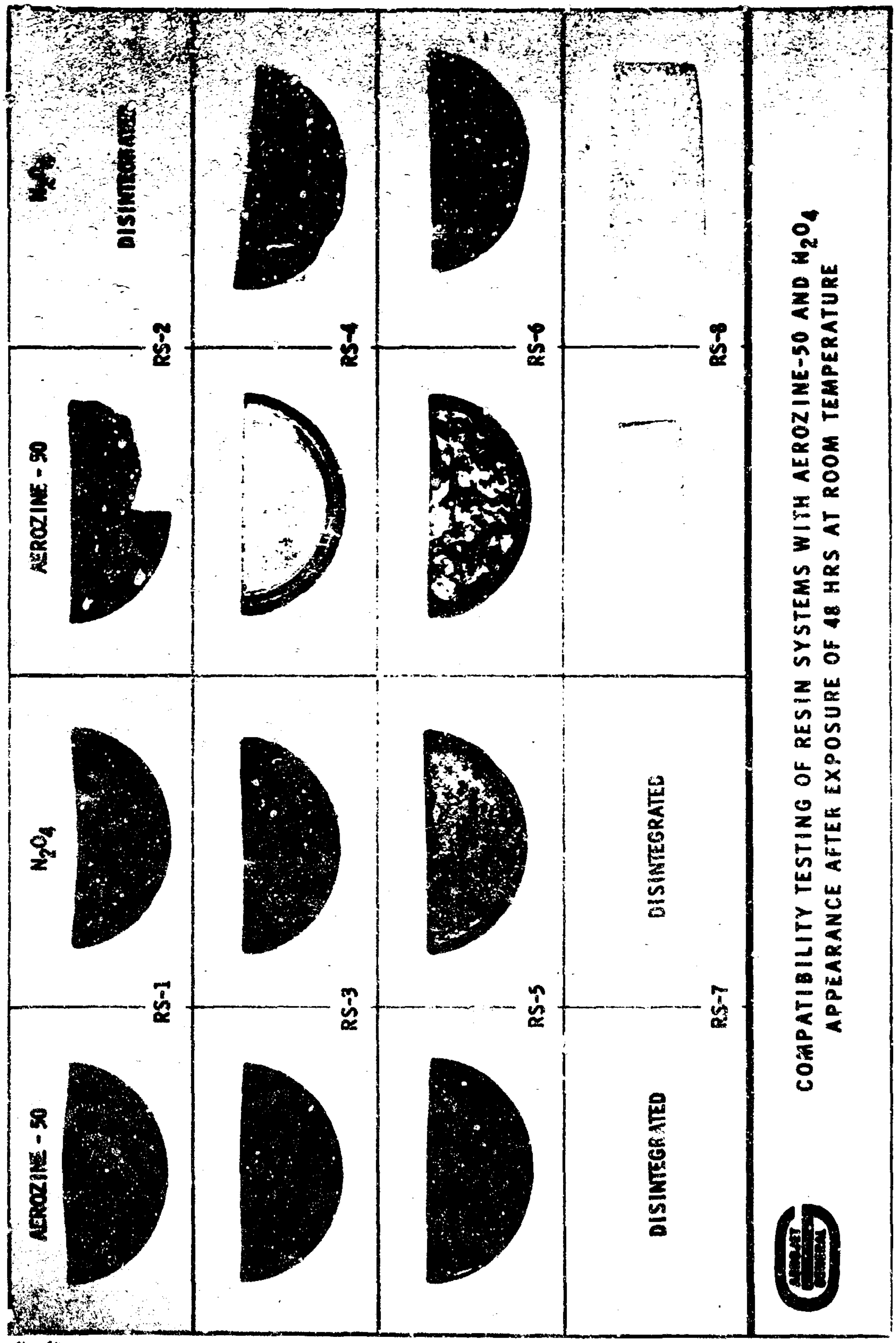
| Metal | Thickness, in. | Time, hours | Temp, °F | Corrosion Rate mils/year | Appearance of Specimens |
|---|---|---|---|---|---|
| Al-Teflon Lamin. | .002/.004 | 163 | 160 | None | Teflon peeled |
| Al-1100-0 | .015 | 163 | 160 | None | No change |
| Al-2024-T3 | .015 | 163 | 160 | 0.5 | Slight discoloration |
| SS 304 | .015 | 163 | 160 | Negligible | No change |
| SS 347 | .015 | 163 | 160 | Negligible | No change |
| Monel | .015 | 163 | 160 | 4.03 | Slight discoloration |

TABLE 6

TENSILE PROPERTIES OF METALS

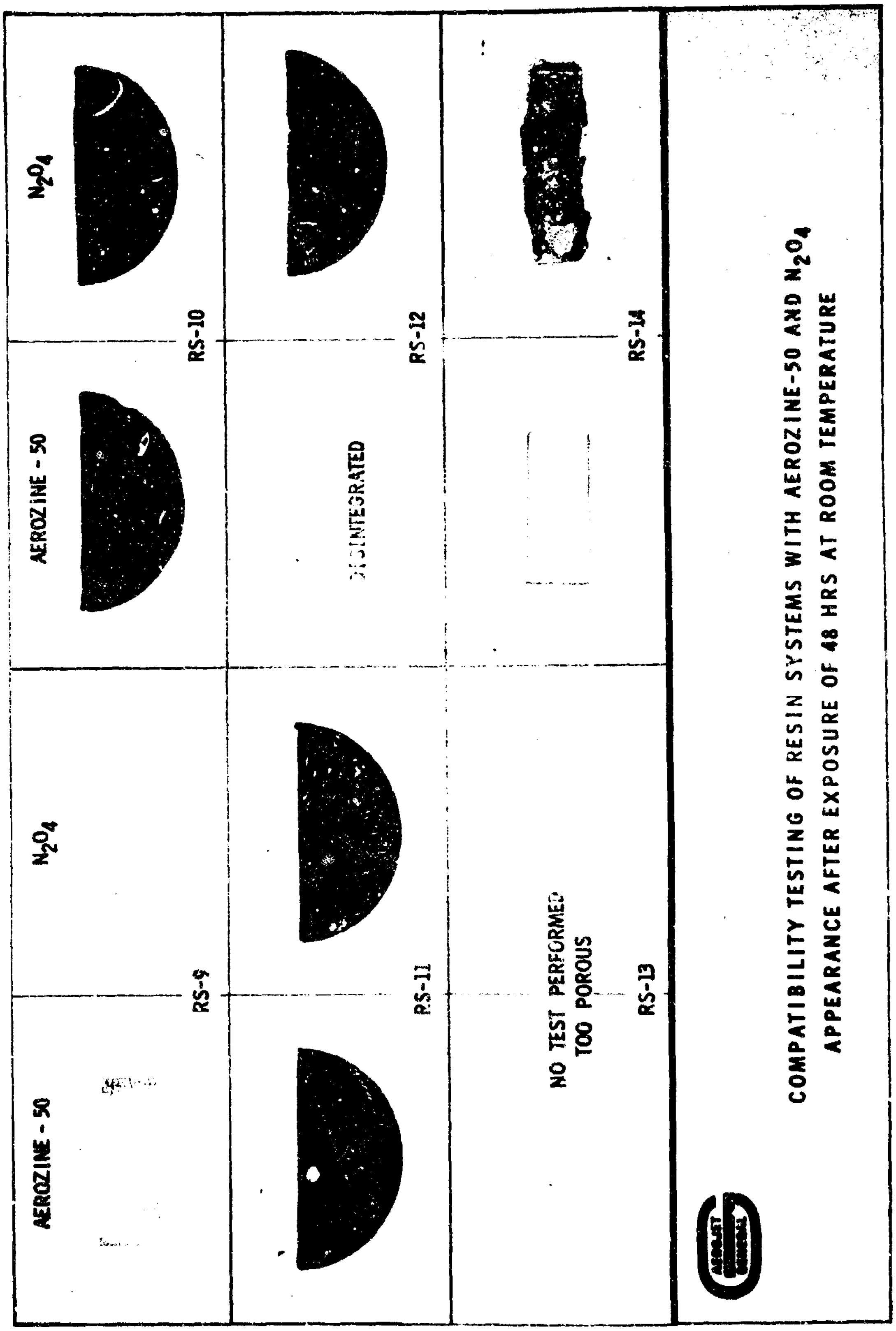
| Material | Yield Strength, psi | | | Tensile Strength, psi | | | Elongation in 2 in., % | | |
|---|---|---|---|---|---|---|---|---|---|
| | -117°F | 80°F | 158°F | -117°F | 80°F | 158°F | -117°F | 80°F | 158°F |
| Al 1100-0 | 5,300 | 5,100 | 5,000 | 15,000 | 13,500 | 12,000 | 46.0 | 42.0 | 47.5 |
| Al 2024-T3 | 46,000 | 44,000 | 43,000 | 775,000 | 67,000 | 63,000 | 25.0 | 21.5 | 22.5 |
| Al 3003-0 | 7,300 | 6,000 | 5,500 | 19,000 | 15,600 | 13,000 | 45.0 | 43.0 | 43.0 |
| Al 3003-H14 | 22,300 | 21,500 | 19,000 | 25,000 | 23,200 | 21,000 | 18.5 | 14.0 | 16.0 |
| Al 3003-H18 | 29,300 | 26,700 | 21,000 | 33,400 | 30,400 | 26,000 | 11.0 | 9.0 | 10.0 |
| Al 7075-T6 | 75,000 | 74,000 | 70,000 | 84,000 | 83,000 | 80,000 | 9.5 | 11.5 | 14.0 |
| St. Steel 304 (ann.) | 39,000 | 35,000 | 31,000 | 155,000 | 85,000 | 80,000 | 37.5 | 60.0 | 60.0 |
| St. Steel 347 (ann.) | 43,000 | 41,000 | 37,000 | 138,000 | 90,000 | 85,000 | 55.0 | 62.0 | 57.0 |
| K-Monel | 40,000 | 30,000 | 28,000 | 100,000 | 86,000 | 85,000 | 54.0 | 49.0 | 49.0 |
| Copper | 13,000 | 8,000 | 6,000 | 38,000 | 32,000 | 29,000 | 46.0 | 40.0 | 35.0 |
| Nickel | 15,000 | 13,000 | 12,000 | 63,000 | 54,000 | 52,000 | 61.0 | 55.0 | 54.5 |

Note: Data obtained from Cryogenic Materials Data Handbook, U.S. Dept. of Commerce - 1961 (Thickness of specimens unknown).




J64-689

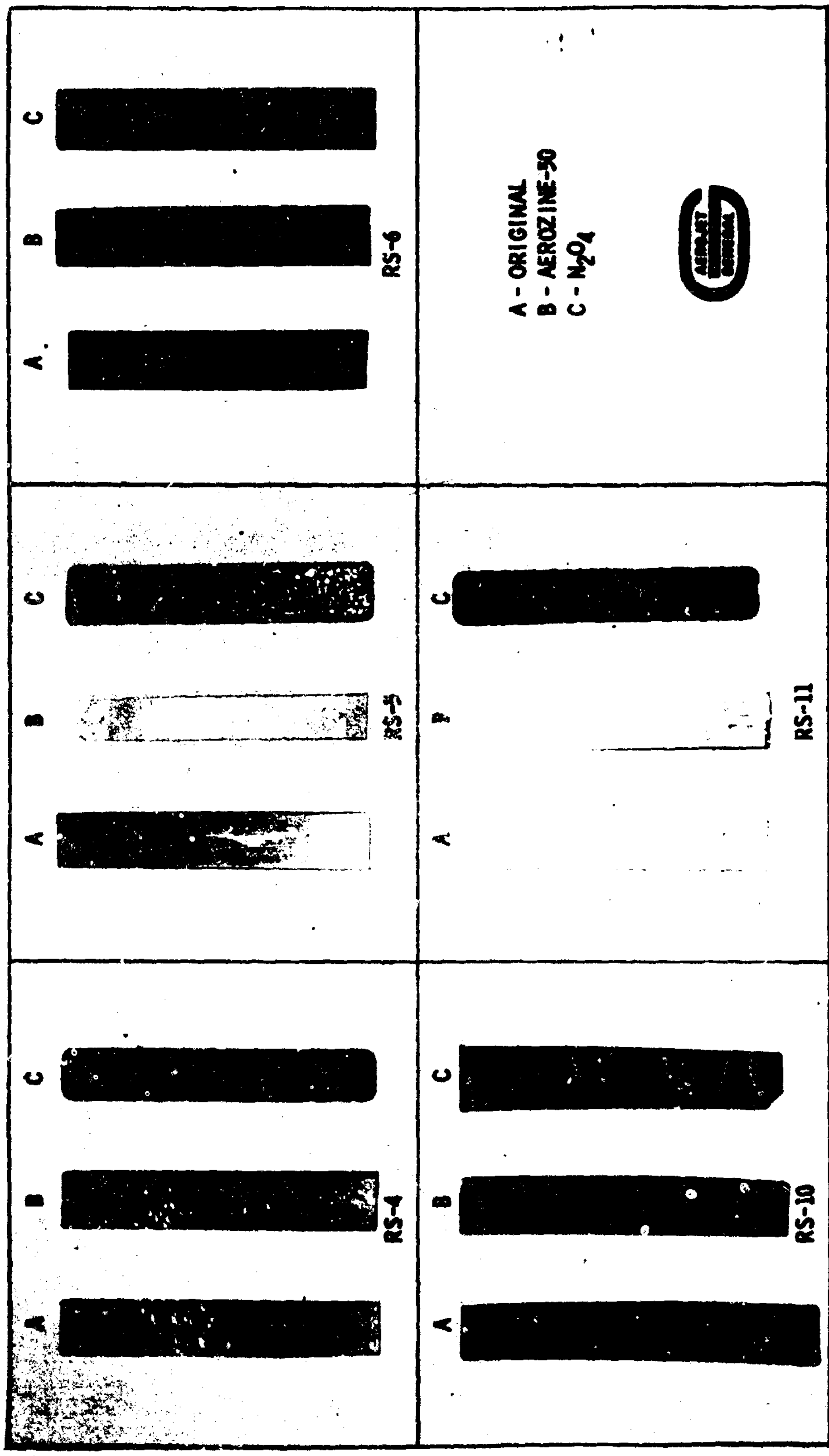
Figure 1




COMPATIBILITY TESTING OF RESIN SYSTEMS WITH AEROZINE-50 AND $N_2O_4$
APPEARANCE AFTER EXPOSURE OF 48 HRS AT ROOM TEMPERATURE

864-690

Figure 1a




COMPATIBILITY TESTING OF RESIN SYSTEMS WITH AEROZINE-50 AND $N_2O_4$
CONDITION BEFORE & AFTER EXPOSURE OF 7 DAYS AT 70 F

864-688

Figure 2